The Orbital Debris Quarterly News

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NEWS

SOZ Ullage Motor Breakup

The 23rd breakup of a SOZ ullage motor occurred in late November and was the year 2000's fourth breakup event (see Orbital Debris Quarterly Newsletter Volume 5, Issue 4, p. 2.) Satellite number 23631 in a pre-event orbit of 147 km by 18,115 km at a 64.4 degree inclination was associated with the 24 July 1995 launch of the Cosmos 2316-2318 satellites. These members of the Gloanass series are equivalent to GPS/Navstar satellites and reside in middle earth orbit. The break-up object was one of two pieces left in the transfer orbit and as of November 21, 2000 had been on orbit 5 years and 121 days. Eight pieces of debris in rapidly changing orbits were detected by the U.S. Navy's electronic fence on 21 November. Risk assessments performed by the Orbital Debris Program Office indicated no threat to the ISS and no long-term effects on the environment. ❖

The Year 2000 Leonids

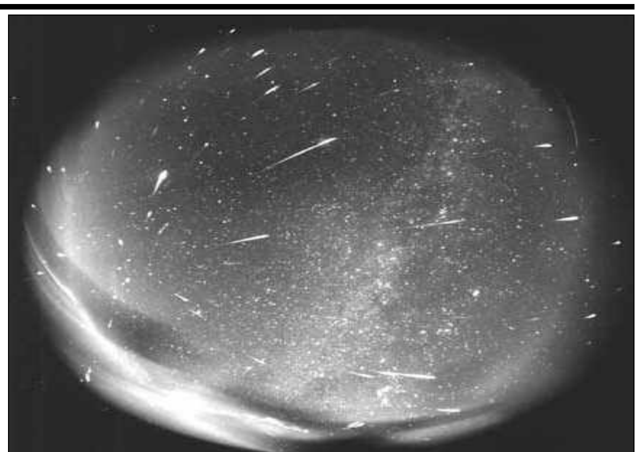
J. Pawlowski

The Leonid activity of year 2000 lived up to experts' predictions of merely being a minor shower. In addition, cloudy skies and a bright Moon hindered observations at most locations worldwide.

Peak activity for the Leonids occurred as predicted during the early morning of November 18th from 0600 to 0800 UT along the Atlantic seaboard from Canada to Brazil. Some observers reported rates slightly over 100 per hour.

Skies were completely cloudy at the Johnson Space Center (JSC) in Houston Texas but approximately five hours of observations by Anna Scott were recorded at the JSC Observatory near Cloudcroft New Mexico from 0700 to 0900 UT on November 17th and from 0700 to 1000 UT on November 18th using our three meter Liquid Mirror Telescope (LMT) with its 0.278º field of view.

No Leonids were detected on Nov. 17th because of cloudy skies. On November 18th our highest number of Leonids (10) in a one hour period was detected from 0700 to 0800 UT. This number is much lower than our highest LMT number in 1999 (32). Seven Leonids were detected from 0800 to 0900 (UT), but increasingly cloudy skies hindered the observation for the rest of the viewing period, 0900 to 1300 (UT). ❖



A photo taken at the Modra Observatory in Slovakia of a Leonid meteor shower.

Inside...

Project Reviews

Collaborative EVOLVE Studies on the LEO Debris

L. Foster, D. Hall, and P. Krisko

NASA orbital debris researchers frequently collaborate with other research groups. Two recent studies providing data to researchers in Japan and India have demonstrated interesting facets of several debris mitigation scenarios and of the NASA/JSC debris environment modeling program EVOLVE 4.0. EVOLVE predicts the evolution in size and altitude, of the spatial densities for objects 1-cm in size and larger, of man-made orbital objects below 2000 km. Spatial densities are determined from the present measured and estimated environment, from future space traffic projections, and from statistical fragmentation and collision processes, using orbital elements which are propagated in a realistic environment.

M. Neish, of NASDA (the Japanese National Space Development Agency), requested a 100-year projection from the present, of the 1-cm and larger and the 10-cm and larger debris flux environment, for the orbit types shown in Table 1, for four mitigation scenarios: (1) no mitigation; (2) safing of payloads and rocket bodies after projection year 10 and end-of-life payload disposal and booster rocket disposal within 25 years after projection year 10; (3) safing of payloads after projection year 10 and end-of-life payload disposal within 25 years with immediate booster disposal after projection year 10; and (4) safing of payloads and boosters after projection year 10 with end of life payload disposal and immediate rocket body disposal after projection year 50.

The standard EVOLVE output is an array of altitude spatial densities, generated in one year time steps. Since the request was for flux with respect to an orbit (i, a, e), it was necessary to convert the spatial densities to flux using the latest orbital debris flux program ORDEM2000. The debris flux changes due to solar cycle induced atmospheric variation were of course much greater at the ISS altitude than at higher altitudes. For all altitudes, higher debris fluxes were observed for higher orbital inclinations, a known effect which is not normally seen in EVOLVE output since the program determines an average spatial density over the earth at a given altitude. As expected, scenario 3 generally showed the lowest fluxes, followed by scenarios 2, 4, and 1, respectively. A striking exception for ISS orbit is shown in Figure 1. At ISS altitude, all mitigation scenarios (2,3, and 4) showed four orders of magnitude improvement over scenario 1 in the 1-cm and larger debris flux after 100 years. However the 10-cm and larger debris flux of scenario 2 proved to be as much as a factor of three higher than that for no mitigation (scenario 1). The 25-year rule implemented in projection year 10 for payloads and boosters resulted in the greater flux at the low ISS altitude. This behavior has been noted in previous studies at NASA and other agencies. However, the added flux of the deorbiting spacecraft should not significantly increase the collision risk at the ISS altitude over time. With the reduced 1-cm and larger debris flux seen in Figure 1, the debris collision risk to an active vehicle in ISS orbit is dramatically reduced when mitigation measures are applied. ISS debris avoidance procedures should provide about a 95% risk reduction from the 10-cm and larger

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Orbit	KSC latitude	ISS,Globalstar	Cosmos	Teledesic	Iridium	Retrograde
Inclination (deg)	28.5	~52	82	84	88	98.5
Altitude (km)	500,600,700, 800,900,1000	370,1410	960,1400	1375	780	500,600,700,800, 850,900,1000

Table 1. NASDA requested flux projection.

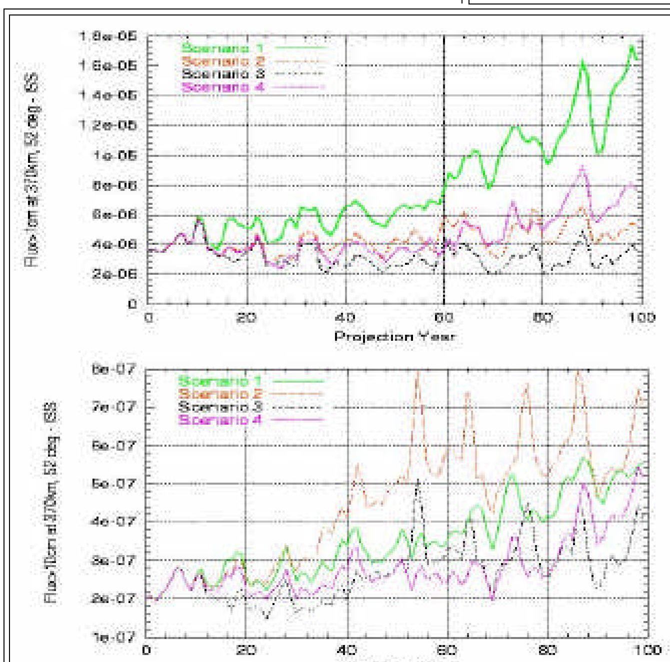

Figure 1. Upper plot shows 1 cm and larger flux at ISS altitude for the four scenarios. The lower plot shows the 10 cm and larger flux.

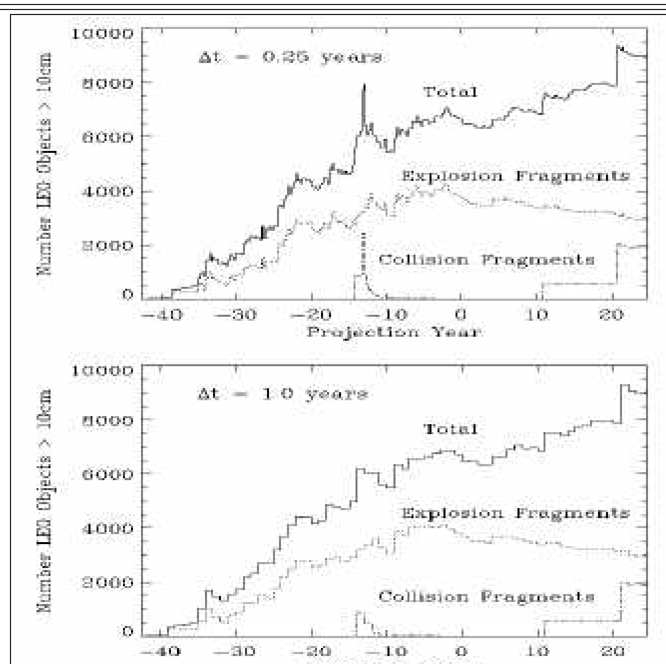

Figure 2. Upper plot in 0.25 time steps. Lower plot in 1 year time steps.

Project Reviews

Flight Readiness Review Report

M. Matney

Before every Shuttle mission, NASA/JSC performs an orbital debris risk evaluation for the Flight Readiness Review (FRR). Primarily, this consists of a detailed analysis of the Shuttle sensitive surfaces with the Bumper code to determine the debris and meteoroid risk to the vehicle and mission. Each mission has a target risk level that can be altered by the vehicle orientation during the mission. This risk calculation is based on the standard debris and meteoroid models and does not take into account short time-scale variations in the collision risk. For this reason several analyses are performed by the Orbital Debris Program Office to estimate any enhancement to the baseline risk for a particular mission.

The first source of possible enhancement is that an annual meteoroid shower could peak during the mission that might temporarily increase the net meteoroid flux over the short two-week Shuttle mission. Currently, we use a model of shower activity based on ground observations to compute a simple meteoroid flux enhancement factor to be added to the Bumper results. Because meteor showers typically last only a few days, it may be possible to shift the launch time of a mission to avoid the strongest outbursts of meteoroid activity such as a Leonid meteor storm.

The second source of possible enhancement is that the Shuttle might fly through a dense region of debris from a recent on-orbit breakup event. This could potentially add an enhanced flux onto the time-averaged ORDEM flux used by Bumper. The SBRAM code is used before each Shuttle mission to compare all recent breakups to the future Shuttle orbit and to look for potential debris cloud enhancements.

During each Shuttle mission, US Space Command performs collision avoidance predictions for all catalogued objects in Earth orbit. The purpose is to give the Shuttle a warning in case an object is predicted to enter a collision warning "box". Currently, this "shoe box" is 10 km long in down-track direction, and 4 km wide in radial and cross-track directions. NASA is assessing a new "pizza box" that is 14 km wide in down-range and cross-track directions, and 2 km wide in the radial direction. Future collision avoidance calculations should include more sophisticated estimates of the actual estimated position uncertainties computed by Space Command.

The FRRs are performed some weeks before the actual mission – too early to compute actual collision probabilities. However, the flight directors like a "heads-up" on the expected number of collision warnings they may expect for the mission. For typical Shuttle missions, this number is less than one, so that the prediction becomes the probability that a collision warning will be issued during this mission. This probability is computed using the latest catalog at the time of the FRR using simple estimates of the collision flux based on average flux models. We are working on improving our ability to make these estimates by using more orbit plane prediction information.

We are always improving the FRR process, and are also assessing how we can provide similar information on a regular basis to the International Space Station program in the future. ❖

Spectral Features Used to Determine Material Type of Orbital

K. Jorgensen

An ongoing investigation continues on determining the material type of small- to medium-sized debris using reflectance spectra features. Knowledge of the physical properties of orbital debris is necessary for modeling the debris environment. Current methods determine the size and mass of orbital debris based on knowledge or assumption of the material type of the piece. By using spectroscopy, one can determine the material type of the piece by comparing the absorption features of its spectra to that of lab spectra for given materials. By isolating three wavelength regions, material types can be placed into three main categories: aluminum, other metals, and plastics. Using these three categories, one can make better-educated assumptions of the material type. The goal of this research is not to improve the models themselves, but to improve the information others use to make the models.

A database of common spacecraft material spectra has been collected and contains currently over 300 types of materials. This database will be used as a comparison library once observations of orbital debris have been taken. The material type will be determined based on comparisons to the library.

As an example of the absorption features seen on spacecraft materials, Figure 1 displays three spacecraft materials, aluminum 1100, carbon epoxy, and steel, over the same wavelength region. The three wavelength regions used to determine material type are 0.5–1.0 µm, 1.5–1.9 µm, and 2.1-2.35 µm. In the first region, aluminum shows a strong absorption feature near 0.8 µm, which makes the material easy to pick out when comparing spectra. Steel, as well as other metals, tends to show a general increase in slope as wavelength increases. Plastics and epoxies of organic nature show absorption features due to C-H and/or O-H in the final two regions in the infrared. Seen in Figure 1 are absorption features in the carbon material due to C-H near 1.6 µm and between 2.1 and 2.35 µm.

In order to determine the effects of the space environment on the reflectance spectra of spacecraft materials, researchers measured materials from returned spacecraft. Measurements of material degradation for returned missions such as the Long Duration Exposure Facility (LDEF), the Passive Optical Sample Assembly I and II (POSA I and II), and the Evaluation of Oxygen Interaction with Materials (EOIM-3) were conducted. The measurements gave insight to the effect of thermal coatings and paints on the reflectance spectra of various materials.

Figure 2 shows a plastic, Polyetheretherketone (PEEK), flown as part of experiment number A0171 in experiment tray A8 on LDEF. This sample was obtained from Marshall Space Flight Center (MSFC); accompanying the sample was a control piece of PEEK. When compared to the control sample the flown sample shows a decrease in the total reflectance as seen in Figure 2. A slight discoloration is seen on the exposed sample near 0.55 µm and was noted visually while testing the sample. A comparison of the strengths of the absorption feature in near 1.7 µm shows the C-H band decreasing in the flight sample. The feature is still apparent and still strong enough to detect through on-orbit observations, but is definitely not as strong as it was prior to flight. The C-H features in near 2.1 and 2.35 µm are both the same strength in the control and flight samples. When the regions deemed necessary for determining the material type of orbital debris through on-orbit spectral measurements are examined, it appears that the space environment does not change significantly the absorption features seen in plastics in those regions.

When the spectra of returned spacecraft

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Project Reviews

Spectral Features Used to Determine Material Type of Orbital Debris,

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materials were compared with the pre-flight laboratory spectra degradation in the samples were seen mostly in the visible wavelengths, while the samples showed similar features in the near-infrared. Overall, the results displayed less degradation on the spaceflight samples than anticipated. The strengths of absorption features were relatively the same in pre- and post-flight measurements. The three wavelength regions chosen, 0.5 – 1 μm, 1.5 - 1.9 μm, and 2.1 - 2.35 μm were proven to be viable regions in their ability to determine the material type of the spacecraft sample using the absorption features.

The next step in this study is to begin examining of the reflectance spectra of debris still in orbit. Along with on-orbit observations, a continual building of the spacecraft material database is very important. As different paints, plastics, and metals are put onto spacecraft, pre-flight and post-flight measurements should be taken. A more detailed study of the various coatings would be ideal as well. Currently, the majority of coatings placed on the metals have been tested, but the plastics and paints should be tested also. Since physical characteristic data on the small- and medium-sized debris is relatively unknown, any information obtained on the material type and thus albedo would help researchers improve models and shields. Continued correlation of radar observations and optical observations coupled with spectral observations would greatly improve the knowledge base of physical characteristics of the debris environment. ❖

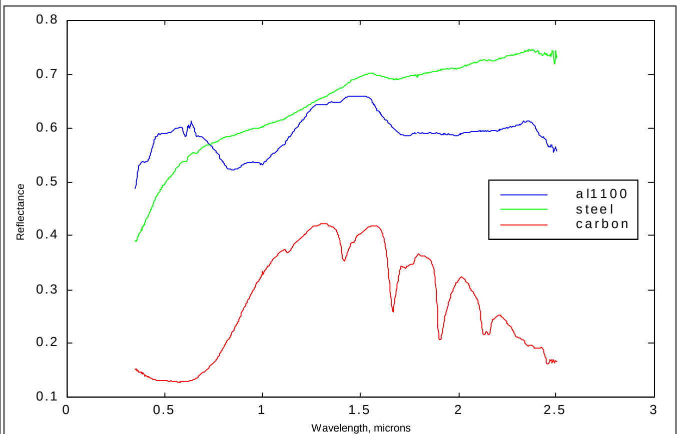

Figure 1. Comparison Spectra of three spacecraft materials: 1100 aluminum, steel, and carbon.

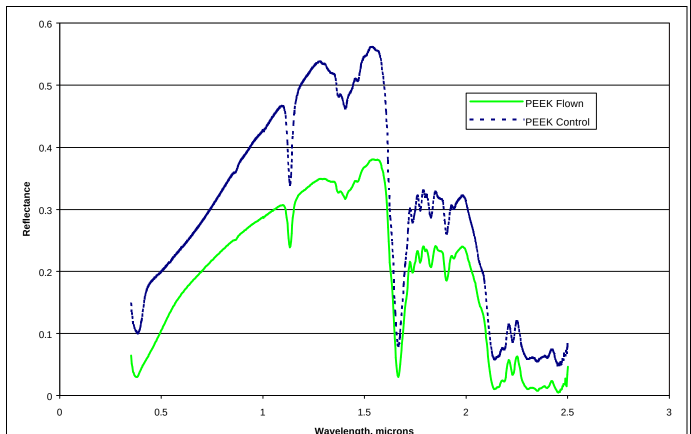

Figure 2: Polyetheretherketone (PEEK) Reflectance Spectra, Control and Flown on LDEF, flown sample reflectance raised by 0.5% to show subtle changes. The x-axis is wavelength in microns and the y-axis is percent reflectance.

ORDEM2000's Debris Environment Model

J.-C. Liou, M. Matney, P. Anz-Meador, D. Kessler, and J. Theall

The new NASA orbital debris engineering model ORDEM2000 has been recently completed and is currently undergoing review. The data sources used in building and testing the model and the method used to derive debris populations from existing data were described in an article in the previous Orbital Debris Quarterly News (Volume 5, Issue 4). Here we describe the method adopted in ORDEM2000 to build the debris environment from the derived debris populations.

Figure 1 outlines the differences between ORDEM2000 and ORDEM96 to derive the model debris environment. Once a debris population is derived, ORDEM96 simplifies the population into 6 inclinations bands and 2 eccentricity families. In addition, ORDEM96 assumes that their longitudes of the ascending node (Ω) and arguments of perigee (ω) are randomly distributed in space. With further assumptions on their size distribution and altitude dependence, a set of equations can be derived to represent the LEO debris environment (Kessler 1981 *ICARUS* **48**, 39-48; Kessler et al. 1996 NASA-TM 104825). One can then take the equations and calculate the impact flux on an orbiting spacecraft or the debris flux expected to be observed by a ground-based telescope or radar.

ORDEM2000 uses a different approach to build the model debris environment. Data files are created to describe the spatial density, velocity distribution, and inclination distribution of debris particles at different longitudes, latitudes, and altitudes. The debris environment is represented by these "template" files. The first step in creating the templates is to divide the LEO space into (5° x 5°x 50 km) cells in longitude, latitude, and altitude, respectively. When a debris population is derived from observations, the resident time of each debris particle within each cell is calculated using the fractional time it spends in that cell. For example, if a debris particle spends 3% of its orbital period within a given cell, 0.03 "object" is assigned to that cell. Once the same procedure is completed for every debris particle in the population, the spatial density of this debris population within each cell is simply the sum of objects within that cell divided by its volume.

No assumptions regarding debris particles' inclinations, eccentricities, or orientations in space (longitudes of the ascending node and arguments of perigee) are required in this approach. Nor is their altitude dependence. However, a decision is made to randomize the longitudes of the ascending node of objects. This is

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ORDEM2000's Debris Environment Model

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justified since the orbital planes of LEO debris particles have fast precession rate, except for sun-synchronous orbits. However, the current distribution in longitude for retrograde orbits is nearly random, so that this approach is justified for these orbits as well.

A velocity distribution is calculated within each cell by evaluating the orbital velocity vector of each population member in the cell. Only the local horizontal velocity component is stored in the templates. This is justified since the radial velocity component is generally less than 0.1 km/s while the horizontal velocity component is about 6-11 km/s. The velocity distribution is stored in both magnitude (between 6 and 11 km/s with an increment of 1 km/s) and direction (10° resolution). The inclination distribution of debris particles of a given size and greater is also calculated for each cell and is saved as part of the templates. The distribution is between 0° and 180° with an increment of 2°.

The spatial density, velocity distribution, and inclination distribution templates of debris particles of six given sizes and greater (10 μm, 100 μm, 1 mm, 1 cm, 10 cm, and 1 m) form the debris environment in ORDEM2000. Once the user specifies the orbit of a spacecraft, the model simply "flies" the spacecraft through the environment and calculates the impact flux from debris particles of six different sizes and greater. A cubic spline interpolation is applied to the output to obtain the flux from any arbitrary size debris between 10 μm and 1 m. A similar function to predict the flux observed by a ground-based sensor is also included in the model.

A potential problem with this new approach is in the grid-size of the cells. One can certainly make the cells smaller and increase the resolution. However, the physical size of the resultant template files may not be manageable by a regular computer. On the other hand, one needs to make sure the grid-size of the cells is sufficient to represent the environment. The template files with the standard resolution in ORDEM2000 have a total physical size of about 14 MB. Is the resolution good enough? To answer this question, a special sensitivity study has been performed. New templates with (1° x 1° x 10 km) cells and (0.1 km/s x 1°) velocity distribution are created and implemented into the model. Average impact fluxes on a spacecraft with a Shuttle-like orbit are calculated using both the standard templates and the special ones. The comparison shows that there is no significant difference between the two. Another study with a spacecraft of ISS-type orbit also shows similar result. These comparisons indicate that the choice of the grid-size utilized in ORDEM2000 is a reasonable one. ❖

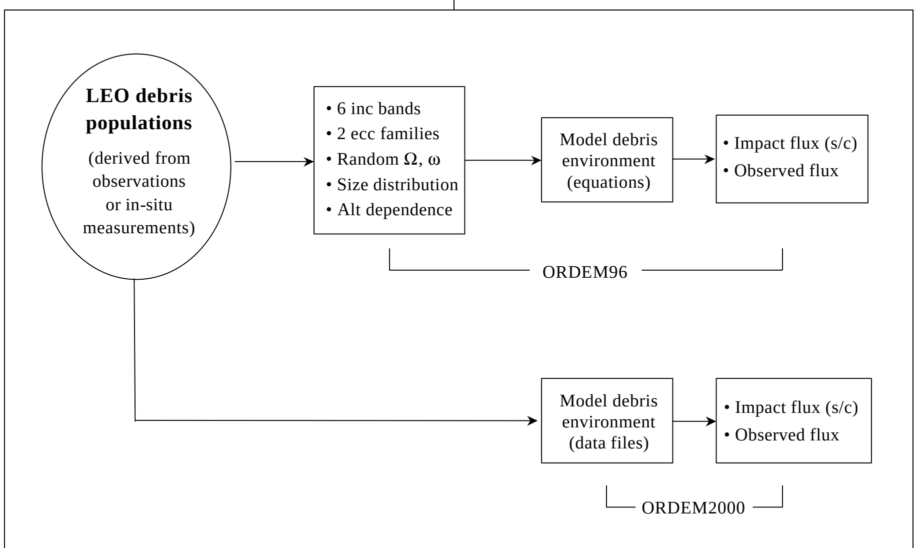

Figure 1. ORDEM96 and ORDEM2000 procedure flowcharts.

Meeting Report

51st International Astronautical Congress

The 51st International Astronautical Congress was held on October 2-6, 2000 in Rio de Janeiro, Brazil. The spectacular city of Rio set an interesting backdrop for a productive set of meetings on orbital debris issues. Over two days of orbital debris sessions, more than 30 papers were presented describing various orbital debris study programs around the world. There were several papers describing the use of optical telescopes to detect debris – especially debris in the GEO regime – reflecting the growth of such instruments becoming available in recent months. Authors also presented papers on the latest developments in European and American efforts to define the debris environment for use by spacecraft designers, as well as modeling efforts to look at growth of the future debris environment. There were also some papers examining the debris susceptibilities and dangers of large tethers in Earth orbit. Throughout many of the modeling papers – whether it was modeling satellite breakups, spacecraft shielding, or the debris environment – there was a keen interest in applying new and different mathematical tools to solve difficult problems. For the most part, the papers presented covered the complete spectrum of studies carried on worldwide to understand the debris environment through modeling, measurements, mitigation practices, and spacecraft shielding design. An interesting change this year was the inclusion of some papers that stepped back to examine the history of orbital debris studies over the last 20+ years and how orbital debris studies have "come of age" – a sentiment clearly reflected in the breadth of the topics discussed. ❖

INTERNATIONAL SPACE MISSIONS

October - December 2000

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2000-059A	GE 1A	USA	35778	35795	0.0	2	1
2000-060A	NSAT 110	JAPAN	35781	35793	0.0	1	0
2000-061A	HETE 2	USA	593	634	2.0	1	0
2000-062A	STS 92	USA	379	390	51.6	0	0
2000-063A	COSMOS 2375	RUSSIA	19121	19139	64.8	2	3
2000-063B	COSMOS 2376	RUSSIA	19126	19134	64.8		
2000-063C	COSMOS 2374	RUSSIA	19035	19225	64.8		
2000-064A	PROGRESS-M 43	RUSSIA	304	325	51.6	1	0
2000-065A	USA 153	USA	ELEMENTS UNAVAIL-			2	0
2000-066A	THURAYA 1	UAE	35754	35818	6.2	1	0
2000-067A	GE 6	USA	35777	35798	0.0	2	1
2000-068A	EUROPE STAR F1	FRANCE	35773	35800	0.0	1	0
2000-069A	BEIDOU 1	CHINA	35773	35803	0.1	1	0
2000-070A	SOYUZ TM-31	RUSSIA	364	375	51.6	1	0
2000-071A	NAVSTAR 49	USA	20106	20727	55.1	2	0
2000-072A	PAS 1R	USA	34687	36974	0.1	1	1
2000-072B	AMSAT OSCAR 40	GERMANY	355	58974	6.2		
2000-072C	STRV 1C	UK	680	39790	6.3		
2000-072D	STRV 1D	UK	602	39264	6.3		
2000-073A	PROGRESS-M1 4	RUSSIA	365	375	51.6	1	0
2000-074A	QUICKBIRD 1	USA	78	610	65.8	0	0
2000-075A	EO-1	USA	701	704	98.2	1	1
2000-075B	SAC C	ARGENTINA	672	707	98.3		
2000-075C	MUNIN	SWEDEN	698	1800	95.4		
2000-076A	ANIK F1	CANADA	EN ROUTE TO OP. ORBIT			1	0
2000-077A	SIRIUS 3	USA	24475	47090	63.4	2	1
2000-078A	STS 97	USA	352	365	51.6	0	0
2000-079A	EROS-A1	ISRAEL	489	503	97.3	1	0
2000-080A	USA 155	USA	ELEMENTS UNAVAIL-			1	0
2000-081A	ASTRA 2D	LUXEM.	35887	35895	0.3	1	1
2000-081B	GE 8	USA	35780	35794	0.1		
2000-082A	BEIDOU 1B	CHINA	35776	35797	0.1	1	0

Upcoming Meetings

19-21 March 2001: *Third European Conference on Space Debris*, Darmstadt, Germany. This conference provides a forum for the presentation of results from research on space debris, to assist in defining future directions for research, to identify methods of debris control, reduction and protection, and to discuss international implications and policy issues. The final program will be available February 2001. For more information contact W. Flury at wflury@esoc.esa.de

3-5 April 2001: *Space Control Conference*, MIT Lincoln Laboratory, Lexington, Massachusettes, USA. The conference is the 19th annual meeting hosted by MIT Lincoln Laboratory on space control issues, surveillance technology (including orbtial debris), and monitoring and identification. For further information contact Susan Andrews at scc@ll.mit.edu

ORBITAL BOX SCORE

(as of 27 December 2000, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies	Total
CHINA	32	338	370
CIS	1331	2553	3884
ESA	30	238	268
INDIA	20	5	25
JAPAN	66	45	111
US	936	2871	3807
OTHER	305	26	331
TOTAL	2720	6076	8796

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Collaborative EVOLVE Studies, Cont'd

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population, which is tracked, while the risk from the 1-cm $\leq$ diameter $\leq$ 10-cm population, which is not tracked and for which shielding is not effective, is reduced by at least a factor of 10^4 by projection year 100.

A. S. Ganeshan, head of the Navigation Systems Flight Dynamics Division at the ISRO Satellite Center in Bangalore, India, requested element sets for the entire estimated debris environment from 1957 until year 2000, and simulated element sets for the entire modeled debris environment, in quarter year time steps, for a future projection of 25 years.

EVOLVE routinely uses one year time steps with an output of spatial densities. The code was modified to run in quarter year time steps and to extract the orbital elements producing the spatial densities. Figure 2 shows for LEO objects 10 cm in size and larger, the total number, the number of explosion fragments, and the number of collision fragments. The transient effects of the P78 SOLWIND and USA19/USA19-RB intentional hypervelocity collisions that occurred in 1985 and 1986 (projection years –14 and -13) are clearly seen in the $\Delta t = 0.25$ year plot. Short-lived breakup fragments can produce a high transitory debris population not observed with one year time steps in the prediction tool, but which can appreciably increase the risk to an orbiting space vehicle. In the plot with time steps of $\Delta t = 1.0$ years, the peak from these events is much less significant than the peak in the fine time step data. ❖